Space Station Freedom Advanced Development Bimonthly Report for SSM/PMAD Automation

Task Title: Power Management and Distribution Automation

WBS Category: Flight Systems

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Significant Events:

During the reporting period of September and October, 1989, several notable milestones were achieved. Foremost, delivery of software for the DC/Star topology change was completed the week of October 16. This delivery allows the highly modified breadboard to be operated by the automation software at about the same level as before the changes in topology and power type occurred. Some obvious bugs were fixed, but the continuing development work is aimed at the mid-1990 delivery on the new workstation and controllers.

All the new hardware has either been acquired or put on order by Martin Marietta. The two Solbourne computers have been delivered to Denver. Five Quimax 80386 computers will be delivered and shipped on to MSFC in the next one or two months, while three more will stay in Denver for development.

A paper describing the intelligent control aspect of the SSM/PMAD breadboard was presented at the IEEE Intelligent Controls Conference by Martin Marietta personnel. Louis Lollar of MSFC also submitted a paper for publication in the Aerospace Applications of Artificial Intelligence Conference, but was not able to attend due to limited travel budget.

Bryan Walls visited Martin Marietta in Denver for a pre-delivery review of progress on the contract. He returned with David Hall, Norma Whitehead, Bob Bechtel, and several MSFC personnel associated with the hardware portion of the contract for an overall strategy meeting for the SSM/PMAD work. These trips were in the last two weeks of September. Seven members of the Martin Marietta team then came to MSFC with the delivery in October.

The communications link between MSFC and LeRC was finally completed in this reporting period. Testing confirmed that computers in the AMPSLAB facility are capable of communicating with machines in LeRC's Power Technology Division. The link uses the TCP/IP protocol over NASA's PSCN-I. LeRC personnel were invited to join MSFC and

Martin Marietta in a meeting to discuss how this resource should best be used to provide cooperation between the two center's PMAD breadboards, but no one was able to come. A proposal was worked up at the meeting, and a copy sent to LeRC, but LeRC has not yet had a chance to concur or disagree with the suggested approach. A copy of what was sent to LeRC is included in the Space Station Freedom Evolution Symposium viewgraphs which are included with the hard copy of this report. It might be best not to include those three viewgraphs in the Annual Report unless it does meet with LeRC approval.

OAST has been undergoing a reexamination of funding commitments, including the funding for cooperating expert systems and intermediate modes of autonomy in SSM/PMAD. Hopefully this will not negatively effect funding levels since a key component of their examination is the level of project support. Since the OAST funding is a major part of funding for SSM/PMAD, it is important that the Space Station Office does show the high level of advocacy that has been demonstrated in the past as OAST asks for input in the coming weeks.

A new MSFC team member has been added to this project. Rajiv Doreswamy will be in charge of the communications effort with LeRC. He has a Masters Degree in Electrical Engineering from Auburn University, and will be a valuable addition to the SSM/PMAD team. The Martin Marietta side of the team is looking for new personnel and are considering hiring a new college graduate.

Lab/Hab Module PMAD

Prepared by
Bryan Walls

for the
Transition Definition
Program Symposium

NASA — SSM/PMAD Overview

--Abstract for Transition Definition Program Symposium--
Space Station Module PMAD System

This project consists of several tasks which are unified toward experimentally demonstrating the operation of a highly autonomous, user-supportive power management and distribution system for Space Station Freedom (SSF) hab/lab modules. This goal will be extended to a demonstration of autonomous, cooperative power system operation for the whole Space Station Freedom power system through a joint effort with LeRC, using their Autonomous Power System.

Short term goals for the space station module PMAD include having an operational breadboard reflecting current plans for Space Station Freedom, improving performance of the system communications, and improving the organization and mutability of the AI systems. In the middle term, intermediate levels of autonomy will be added, user interfaces will be modified, and enhanced modeling capabilities will be integrated in the system. Long term goals involve conversion of all software into Ada, vigorous verification and validation efforts, and, finally, seeing an impact of this research on the operation of Space Station Freedom.

Conversion of the system to a DC Star configuration is now in progress, and should be completed by the end of October, 1989. This configuration reflects the latest SSF module architecture. Hardware is now being procured which will improve system communications significantly. The Knowledge Base Management System (KBMS) is initially developed, and the rules from FRAMES have been implemented in the KBMS. Rules in the other two AI systems are also being grouped modularly, making them more tractable, and easier to eventually move into the KBMS.

Adding intermediate levels of autonomy will require development of a planning utility, which will also be built using the KBMS. These changes will require having the user interface for the whole system available from one interface. An Enhanced Model will be developed, which will allow exercise of the system through the interface without requiring all of the power hardware to be operational. The functionality of the AI systems will continue to be advanced, including incipient failure detection.

Ada conversion will begin with the Lowest Level Processor (LLP) code. Then selected pieces of the higher level functionality will be recoded in Ada and, where possible, moved to the LLP level . Validation and verification will be done on the Ada code, and will complete sometime after completion of the Ada conversion.

SSM/PMAD Approach to Automation

- Use fast, simple, dependable hardware at the lowest level as the "first line of defense".
- Provide adequate sensors to understand the system state.
- Distribute processors through the system to control low level hardware, gather sensor data, and communicate with higher level control.
- Coordinate system-wide activity through intelligent central controller(s).

SSM/PMAD Approach to Automation

Circuit breakers are very effective at quickly safing a power system. They represent the only technology available which can react in time and also be remotely controlled and monitored. Though conceivably a very fast computer could read sensors, recognize high current, and order a switch open before damage could occur, it is unlikely with today's technology, less reliable than circuit breakers, and offers no advantage over a remotely switchable circuit breaker.

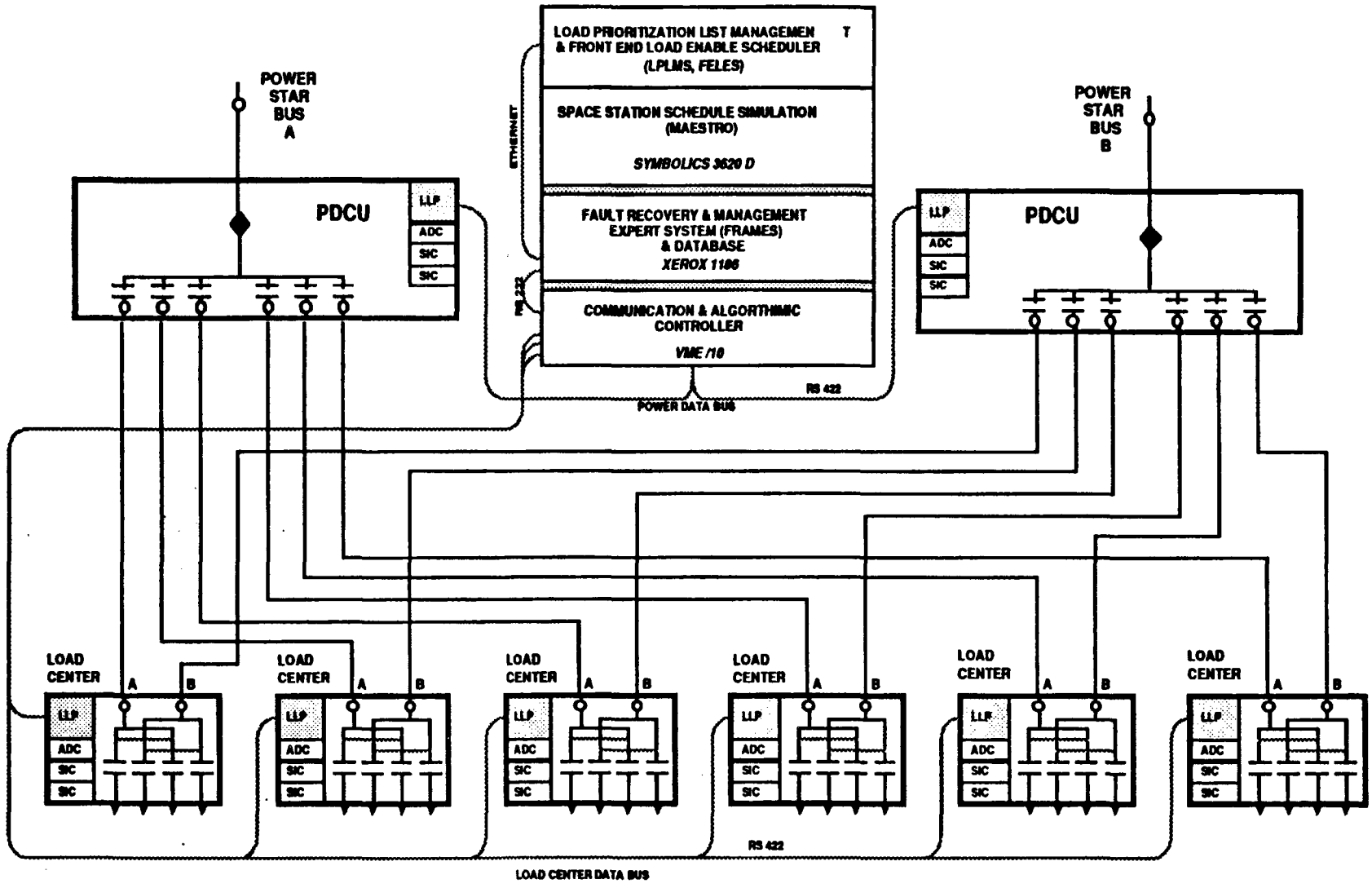
Knowledge of the actual state of a system is necessary for effective control. Determining sensor locations and designing them into the system, instead of adding them on later, reduces the cost and increasing the reliability of the system as a whole.

A problem with numerous sensors is the flood of data they produce. What does one do with it? The answer proposed here is to sort it out locally, and only pass up summaries unless more is needed. Often "situation nominal" is much more relevant than a stream of data, no matter how accurate.

The central controllers act as an interface for human users, put system in an acceptable state if a problem occurs, assist users in identifying and correcting problems, record and allow modification of the system configuration, and provide the lowest level processors the data they need for normal operation.

NASA

SSM/PMAD Overview



SSM/PMAD Topology

Lower Level Autonomy

- Remote Power Controllers (RPCs) provide immediate protection.
- RPCs are grouped into Load Centers. Load Centers are controlled by Lowest Level Processors (LLPs).
- LLPs execute a schedule which is downloaded to them.
- LLPs shed loads which use more than scheduled power.
- LLPs can switch loads to the secondary bus when necessary.
- LLPs communicate with higher level controllers through the CAC.

Lower Level Autonomy -- Switches, Sensors, LLPs, and CAC

The RPCs designed for this breadboard actually consist of two parts: a power stage, which is a switch with resetable over-current protection and a current sensor, and a Generic Card (GC). The GC uses a state machine to offer protection against I^2t, under-voltage, and ground faults, and to communicate with the Switch Interface Card (SIC) and the power stage. Individual sensors are attached to an A-to-D converter which is also attached to the SIC. Each Lowest Level Processor (LLP) communicates with up to two SICs in a Load Center -- one for each bus.

The LLP turns RPCs on or off according to a schedule downloaded to it. It also monitors all the sensors and RPCs. If an RPC trips, the LLP notifies FRAMES of the kind of trip as part of a full status update. The LLP performs in the same way if an RPC is using more power than it is scheduled for, even if the level wouldn't trip the RPC. The LLP orders that RPC off and reports the fault. If the schedule marks an RPC as redundant, the LLP will attempt to turn on a load's redundant RPC if the primary one trips or is shed. Finally, the LLP stores a priority list for it's loads so, in the event of a reduction in system power, lower priority loads will be shed first.

The Communications and Algorithmic Controller (CAC) acts as the communications interface between the LLPs and the higher level controllers. It is the central control point in manual mode operation.

FRAMES

- Monitors breadboard, reporting anomalies to user and to Maestro.
- Evaluates anomalies to determine if failure has occurred, and attempts to diagnose failure.
- Notifies user and other expert systems of conclusions, including any switches considered out of service.
- User interface allows examination of breadboard sensor reading and switch statuses.
- Uses rules developed through work with Power Engineers.
- Coordinate system-wide activity through intelligent central controller(s).

Fault Recovery and Management Expert System (FRAMES)

FRAMES is one of the three AI systems in the SSM/PMAD breadboard. Each LLP notifies FRAMES any time it recognizes an anomaly, such as tripped breakers or shed loads. Messages giving sensor readings are also sent to FRAMES. FRAMES uses the information which comes to it to characterize the system state. If a failure is diagnosed, it notifies the user via its user interface, and sends a message to Maestro, the system scheduler. Components are marked failed. if it is believed they are broken, or out-of-service if they are not usable (eg. a circuit-breaker above is failed). This information is passed on to Maestro for use in rescheduling.

The FRAMES user interface shows the whole system state. Every switch and sensor in the system is displayed, and shows whether or not it is powered, failed, or out-of-service. Switches also show whether they are opened, closed, or tripped. Components are mousable for further information, including sensor values and values of various flags.

Maestro

- Maestro is a resource scheduler.
- Maestro can schedule numerous activities with multiple constraints.
- Dynamic rescheduling may be done in the event of a fault.
- Maestro will be modified to allow negotiation with the LeRC scheduler.

Maestro

Maestro is a resource scheduler which can schedule numerous activities using multiple constraints. In the SSM/PMAD breadboard the constraints currently used include number of crew members required, equipment resources, and power resources. Power is allocated not just by how much is available to the whole system, but also by the ability of intervening components to supply the power.

Maestro's interface converts the schedule into a list at the component level. Information includes start and stop times and upper and lower power levels at each component.

Dynamic rescheduling may be done in the event of a fault. Maestro has access to Activity, Schedule, and Equipment Libraries, and uses encoded knowledge gained from expert schedulers to schedule within constraints.

LPLMS

- The LPLMS periodically notifies the breadboard of the relative priorities of each of the loads.
- This list is updated every 15 minutes.
- The list can be used to prevent high priority loads from being shed in case of a reduction in available power.
- LPLMS can manage dynamic priorities of up to 500 electrical loads.

Load Priority List Management System (LPLMS)

The third of the AI systems, the Load Priority List Maintenance System (LPLMS) uses information from the event list and the activity library, along with its own rules, to dynamically assign relative priority to each active load in the system. A new list is sent down to the LLPs at least every 15 minutes (less than 15 if a contingency occurs). The load priority list can be used to shed loads in case of a reduction in power.

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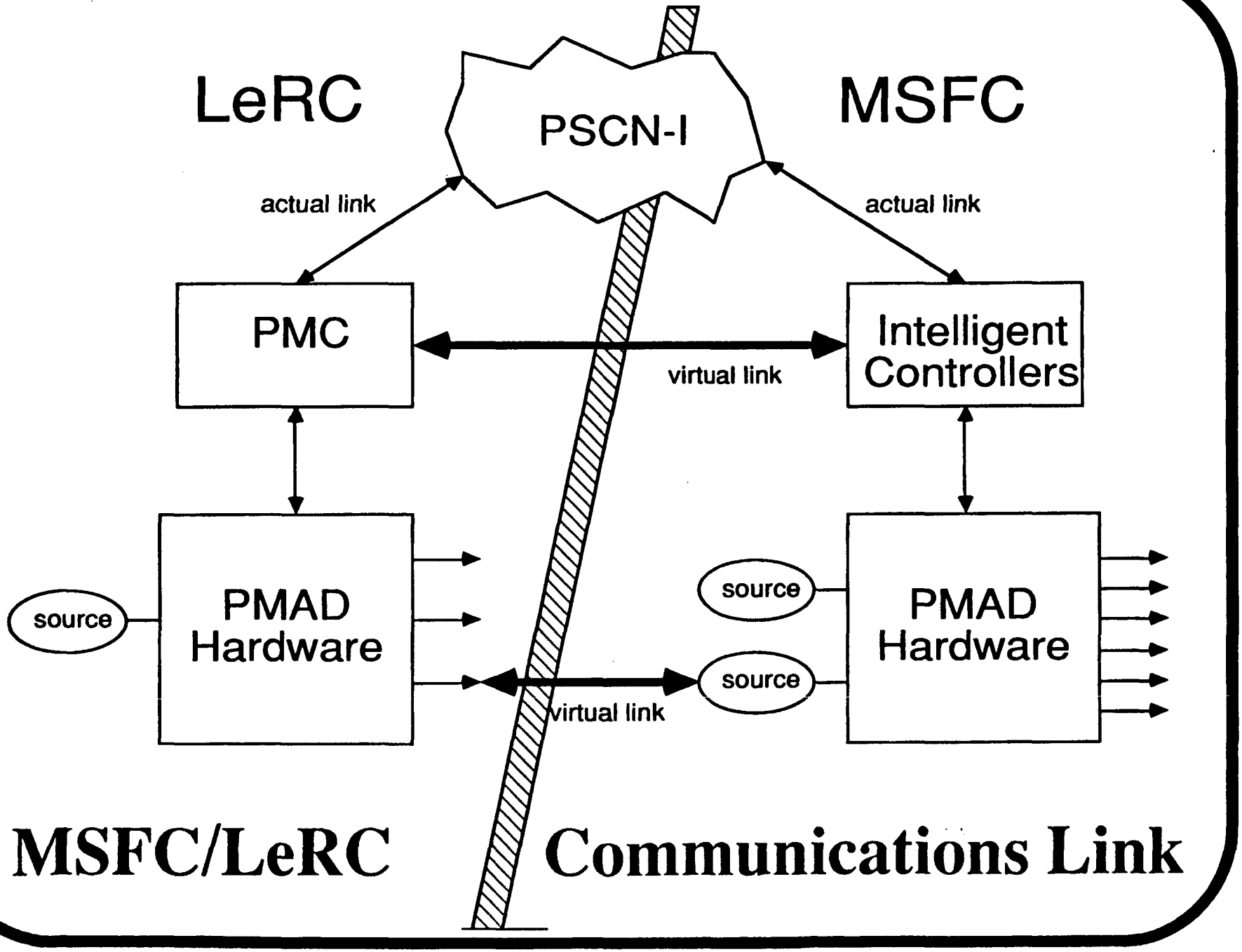
SSM/PMAD Overview



MSFC/LeRC Communications

- A virtual link between the intelligent controllers allows negotiation for power resources.
- A second virtual link between one of the LeRC load and a MSFC source allows emulation of a single breadboard.
- Each breadboard can still be operated independently.
- The actual communications link is available using TCP/IP on the PSCN-I.

NASA

SSM/PMAD Overview

Proposed MSFC/LeRC Communications

A communications link is now available between MSFC's AMPSLAB facility, which includes the SSM/PMAD breadboard, and the Lewis Research Center Power Technology Division laboratory, with their Autonomous Power Expert System (APEX). Two virtual links are envisioned between the two PMAD systems.

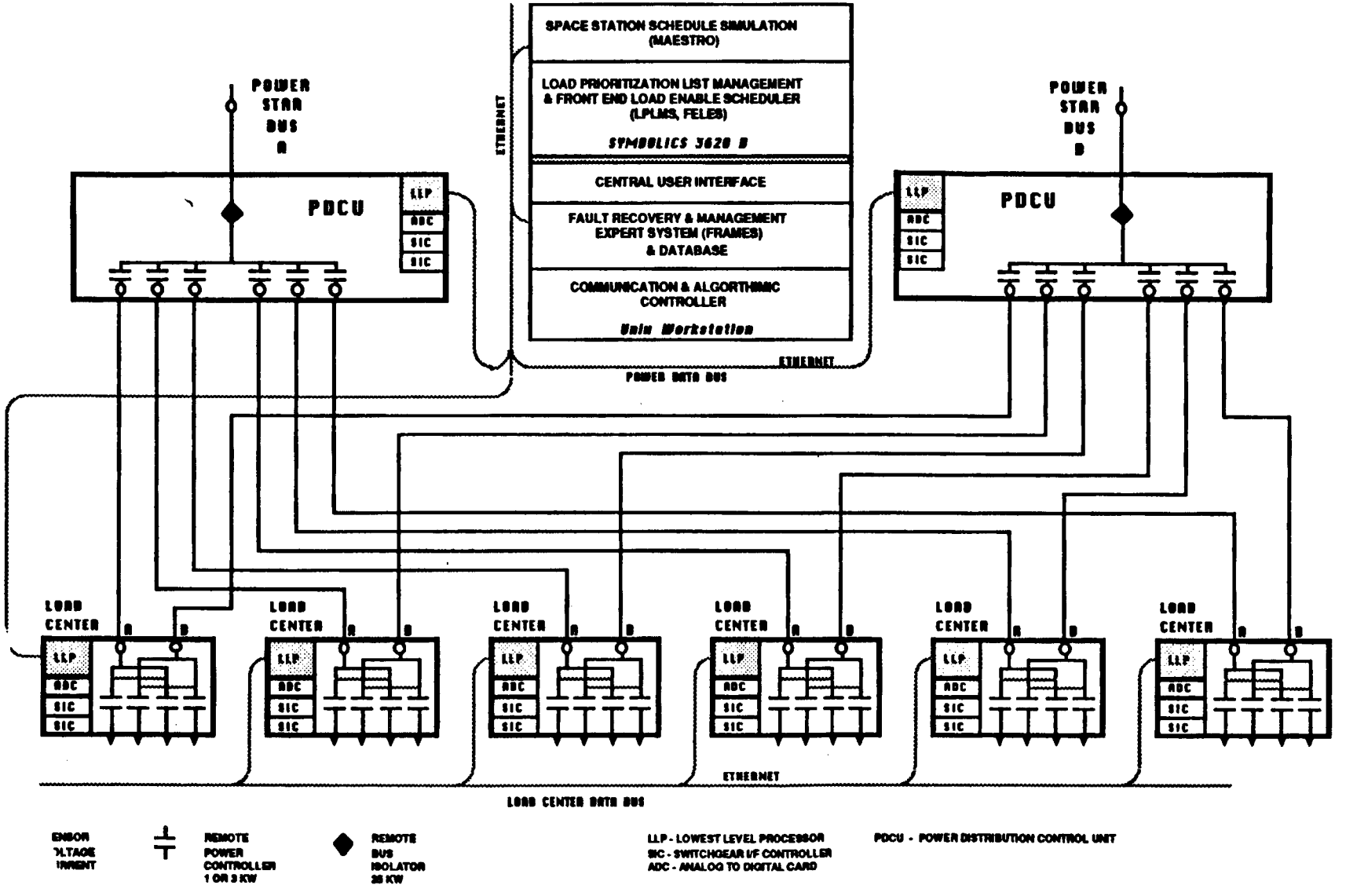
The first link will involve the schedulers for the two systems. Initially interaction will be limited to a request for some level of power from SSM/PMAD for each of the two power buses. APEX would then assign levels, possibly different from those requested, for the buses. As the systems mature, the negotiation will become more sophisticated; SSM/PMAD will provide justification for its request, and APEX will be expected to compare SSM/PMAD's request with those from it's other loads to provide an overall "fair" schedule according to balanced priorities.

The second proposed link will be between one of the loads on the APEX brassboard and one of the dc sources on the SSM/PMAD system. The power drawn by the load will be varied to reflect the power being used in the SSM/PMAD breadboard, thus emulating a single end-to-end power system.

The actual communications link between the centers is via TCP/IP using the PSCN-I service. Both virtual links will be built on this connection, though the second connection may initially be done manually, with communication by telephone.

Planned Changes to SSM/PMAD

- The LLP, CAC, and FRAMES will have new platforms with improved communications.
- FRAMES is being transferred into a new KBMS. Maestro and LPLMS will follow.
- Intermediate levels of autonomy will be added.
- Consolidated, improved user interface will be added.
- Eventual translation to Ada, starting with the lower level autonomy, in two to three years, along with V&V is planned.



Modified Topology

Planned Modifications to SSM/PMAD

By the middle of 1990, some fairly major changes to the automation portion of the SSM/PMAD should be in place. These include a new unix-based computer to host both the FRAMES and CAC functions, 80386 computers with Ethernet to replace the current LLP processors, and some major changes in the structure of FRAMES, with it rehosted in a powerful Knowledge Base Management System environment. The user interface will be significantly upgraded, also.

Under OAST funding, research is under way in how to improve cooperation among the three expert systems, and in adding intermediate modes of autonomy. In the current system, the user has the choice of autonomous operation, or of taking over the whole system. The intermediate modes will provide choices between these two extremes, so a user can have the help of an intelligent assistant.

As the system matures and stabilizes, portions will be transferred into the Ada language, running on general purpose processors. Stricter validation and verification will be observed than is desirable in the present prototypical phase. At the close of this phase, the system should be mature enough to be moved into the mainstream of the Space Station Freedom Program.